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A Proof of Concept of an Airborne Visibility Indicator

By Arthur Estrada, Patricia A. LeDuc, James L. Persson, Joanna L. Greig,
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Aircrew Health and Performance Division

April 2004

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13. ABSTRACT (Maximum 200 words)

Every year U.S. Army and civil aviation loses lives and aircraft due to spatial disorientation experienced during periods of minimal visibility or inadvertent entry into instrument meteorological conditions. Flights sometime end catastrophically when an aircraft flies into terrain or water. It is the duty of the pilot-in-command of a single-aircraft mission, or of the air mission commander in a multi-aircraft operation, to determine the prevailing visibility through which they will be traveling. U.S. Army rotary-wing pilots have always had to use their judgment and experience to subjectively assess the enroute visibility. As weather deteriorates, pilots must rely on their subjective analysis to formulate a course of action: to proceed, alter, or abort the mission.

Advances in state-of-the-art technologies may be able to provide military and civil pilots with objective visibility data presented via a cockpit instrument (an Airborne Visibility Indicator (AVI)) which could provide the necessary objective real-time information from which an informed decision to proceed with or abort a mission can be made. Prior to the actual expense of developing such an instrument, this proof of concept project was conducted to determine if such a concept was practical, would enhance situational awareness, and serve as a countermeasure to inadvertent entry into visual conditions conducive to spatial disorientation (SD).

In general, data from this proof of concept investigation indicated that an AVI would be a useful tool, was favorably received by crews, and was a countermeasure to SD. Based on the findings and conclusions of this proof of concept project, it is recommended that the development of an AVI be continued and a USAARL Small Business Innovative Research (SBIR) proposal topic be submitted for consideration.

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Introduction

Spatial disorientation (SD) occurs "... when the aviator fails to sense correctly the position, motion, or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the earth and gravitational vertical" (Benson, 1978). SD remains an important source of attrition in military flying. U.S. Army Field Manual 3-04.301 (Department of the Army, 2000), Aeromedical Training for Flight Personnel, states that, "Spatial disorientation contributes more to aircraft accidents than any other physiological problem in flight." Regardless of their flight time or experience, all aircrew members are vulnerable to SD. According to the U.S. Army Safety Center (USASC) accident files and a report published by the U.S. Army Aeromedical Research Laboratory (USAARL) (Braithwaite, Groh, and Alvarez., 1997), SD was considered to be a significant factor in 291 (30 percent) of Class A, B and C helicopter accidents in the U.S. Army between 1987 and 1995. According to the report, during this time, 110 lives were lost and a cost of nearly \$468 million was incurred. The monetary cost of SD is high and the fatality rate is between one and one-half to two times that of nondisorientation accidents. The objective of the study was to determine if the use of an airborne visibility indicator (AVI), providing real-time, objective visual data to the flight crew, increased situational awareness and, thus, prevented entry into atmospheric visual environments that make SD more likely to occur.

Background and military relevance

Preliminary results of a review of SD accidents for fiscal years (FY) 1996 through 2000 were presented at the "Recent Trends in Spatial Disorientation Research" Conference, held in San Antonio, Texas (Leduc, 2000). These results showed similar trends with reviews by Durnford et al. (1995) and Braithwaite, Groh, and Alvarez (1997). It was further stated that data comparison with FY's 1991 through 1995 showed that the SD accident rate is not decreasing, and if anything, since 1995, has slowly started increasing. This trend indicates that despite the best efforts of the USASC to educate the aviator through printed accident reviews and the efforts of the developers of improved aircraft orienting technology (cockpit head-up displays, improved night vision devices, global positioning navigation systems, etc.), there has been little change in the SD accident rate.

The goals of the above-described efforts are to enhance the aviator's knowledge and situational awareness, not to teach an aviator to fly while spatially disoriented. The promise of achieving these goals is to prevent the aviator from entering those conditions that are conducive to SD. Every year Army aviation (and civil aviation, for that matter) loses lives and aircraft due to the spatial disorientation experienced during periods of minimal visibility or inadvertent entry into instrument meteorological conditions. The flights sometimes end catastrophically when the aircraft flies into an unseen mountain or other unyielding surface. According to a Federal Aviation Administration technical report (Kirkham et al., 1978), for all fatal accidents in small fixed-wing aircraft from 1970 through 1975, 22.2 % involved continued flight into adverse weather while operating under VFR (visual flight rules) and 16.4 % were attributed to SD.

An important action required by pilots in order to maintain situation awareness and avoid visual conditions likely to cause SD is to correlate actual enroute visibility with the minimum

visibility required for a particular class of airspace or with a mission's minimum visibility as an abort criteria. In the case of classes of airspace that allow VFR flight as defined in the Federal Aviation Regulations (U.S. Government, 2003), when flying VFR, it is incumbent on aviators to maintain at least the minimum visibility required for that airspace. During tactical missions, especially at night involving multiple aircraft, when civil visual flight rules may not apply or may be too lenient, an aviation unit commander, or his/her representative, must establish a set of criteria that requires the mission to be aborted should any of the criteria be met during the conduct of the mission. Examples of these criteria are maximum wind velocities, minimum cloud levels, enemy detection and concentrations, equipment malfunctions, and atmospheric visibility. The commander bases these criteria on objective and subjective assessments of his/her unit. Hence, different units have different criteria. Obviously, if a mission required at least three aircraft and all but two malfunctioned, the mission abort criterion for the number of aircraft would be met and the mission would have to be aborted (objective criterion). On the other hand, the commander must establish subjective criteria, also. In establishing these subjective abort criteria, the commander, for example, would determine the minimum/maximum conditions under which he/she believes that the aircrews of that unit would be able to successfully complete a given mission. (Certainly, a highly trained, experienced, group of aviators would be able to perform and complete a mission under more difficult and demanding conditions than a group of less experienced aviators.) Frequently, these mission abort criteria are incorporated in the unit's standing operating procedures (SOPs) and are standardized for consistency, clarity and brevity. These criteria always, and necessarily, include the minimum atmospheric visibility required for a mission.

Therefore, it is a duty of the pilot-in-command in a single-aircraft mission or of the air mission commander in a multi-aircraft operation to determine the prevailing visibility (greater than 180° of the horizon), or at least the visibility of the sector through which they are traveling (a 45° arc of the horizon circle) (Department of the Air Force, 2001), during the conduct of a mission to ensure that the minimum visibility for that mission has not been exceeded. U.S. Army rotary-wing pilots have always had to use their judgment and experience to subjectively assess the enroute visibility during a flight. Every aviator has struggled at some point during his/her career to meet VFR and/or mission minimum visibility requirements. As weather deteriorates, the pilot must rely on his/her subjective analysis to formulate a course of action: to proceed, alter, or abort the mission. Often, the aircrews proceed into these potentially dangerous conditions, not because the crews are negligent or irresponsible, but because of an honest effort to accomplish the mission and because there is no sure way to know the exact visibility during the flight, especially at night and/or while using night vision goggles (NVGs).

The Army aviator's ability to estimate visibility during flight comes through experience. During initial pilot training, the aviator does not receive a formal course of instruction in estimating atmospheric visibilities. He/she learns this skill through mentorship and trial and error. Most aviators rely on the ability to see a known object through the visual obscuration and attempt to judge the distance. Some aviators use relative distances and/or map cross-referencing (plotting one's position and measuring distance to the visual object). These estimates can vary widely from one aviator to another within the same aircraft or from aircrew to aircrew within a multi-aircraft formation.

The difficulty in estimating visibility with any degree of accuracy is due to the many variables involved. Of course, the absence of standardized formal training is one contributing factor. Other factors include the pilot's own visual acuity and contrast sensitivity (McLean, 2003). Burlov, of the former Soviet Union (1973), concluded, "The natural variability of the contrast sensitivity threshold of the eye causes a large error in the visual estimation of the range of visibility." In another Soviet report regarding contrast sensitivity, Rasskazov (1975) wrote, "The value of the threshold of the contrast sensitivity of eyesight depends on the conditions of observation. Its dependence on the angular dimension and brightness, on the age and degree of training of the observers and a number of other factors is well known." Although small in aviation, some differences do exist in each aviator's ability to focus and perceive distant images (McLean, 2003). According to McLean, some pilots are more inclined to make rapid judgments based on their perceptions while others are more patient and thoughtful. The complicating effects of the NVGs, due to their monochromatic nature (shades of green), cause contrasts to be less noticeable. Their ability to amplify light allows some obscurations to be easily "seen through." Research conducted at the USAARL (Rabin, 1996) concluded: "Recognition of a complex, illusory form is constrained by the visibility of the stimulus, rather than by the particular pathway utilized from eye to brain." The report continues: "That few observers recognized the [illusory form] under simulated NVG conditions underscores the fact that the visual environment can be limited through image intensifiers [NVG]." "Object recognition in a degraded visual environment initially is limited by the visibility of the stimulus, but ultimately determined by the perceptual expectation, vigilance, and experience of the observer."

As a group, it is likely that meteorologists are the most experienced and proficient at estimating prevailing and sector visibility using eyesight. The U.S. Air Force, which provides meteorological services to the Army, operates under the procedures prescribed in Department of the Air Force Manual 15-111 (2001). Visibility observations are made on the basis of normal vision; i.e., without the aid of optical devices such as binoculars or telescopes. Observations are made at an eye level of 6 feet above the ground (an internationally recommended practice). The manual directs observers to select markers (objects) such as buildings, chimneys, hills, trees, and towers that are at verified distances and, thus, if the object is visible, there exists at least that distance of visibility. Although the above-described procedure is accepted as accurate, the reported areas are limited to those areas that are actually observed and, for example, are not necessarily predictive of the areas along a 100-mile flight path. Because these observations are determined by human evaluation, the information may be flawed. Burlov (1973), reported that "the random value of [the contrast sensitivity threshold of the eye] must be considered from two viewpoints. First, it is the direct cause of an error during the visual and visual-instrumental determination of the range of visibility. Second, it can cause differences to arise between the range of visibility set forth by the meteorologist and the range of visibility in the perceptions of the operator-user" [the aviator]. Burlov goes on, "The information issued by the meteorologist contains errors. However, it is also obvious that because of the variability of the contrast sensitivity threshold of the operator-user's eye, the range of visibility he estimates undergoes random fluctuations, including in the invariable external conditions..." "Thus, what we usually call the error in the information issued is the sum of the error of the original information and the operator-user's error. The former characterizes the quality of the meteorological support, while

the latter has no relationship to the meteorological support. It arises due to the subjectivism of the operator-user which randomly appears."

It was out of the scope and intent of this project to discuss in detail the theory and fundamentals of light and the instruments that are used to measure visual range. This project was proposed in an attempt to prove the *concept* of having reference to such an instrument onboard a flying aircraft. The findings of this "proof of concept" project may result in the demonstrated need for an AVI, which will then allow for submission for consideration of an AVI as a USAARL Small Business Innovative Research (SBIR) proposal topic. At that time, details regarding the actual design, data presentation, automatic and manual modes of operation, audio alarm augmentation, head-up display (HUD) integration, and device ergonomics will be addressed and/or specified. With this in mind, the following cursory discussion of some current and prototypical visibility-measuring instruments may be useful.

In order to eliminate the inherent human errors delineated previously and to provide objective visibility data, instruments can be, and are, used to determine visual ranges. According to "A Report on Atmospheric Obstructions to Visibility" (Lujetic, 1979), there are a number of instruments developed and used for the measurement of visual range. The basic attenuation mechanisms are scattering and absorption. Scattering is the process by which a particle in the path of an electromagnetic wave continuously abstracts energy from the path incident wave and reradiates that energy. Absorption is the process by which agents in the atmosphere abstract energy from a light wave. These measuring instruments can be separated into general categories: 1) those that measure the scattered light by sampling a small volume of air using a source and receiver, and 2) those that determine the transmittance of a path of known length using a light source and a telephotometer. Back-, side-, and forward-scatter meters are examples of the first type; and transmissometers are examples of the second.

The instruments above are generally used in fixed applications, i.e., at airports or weather observing stations. In other words, these instruments are stationary and measure the visual range (presence of obscurations) over fixed distances. In applications involving a moving instrument, however, as would be necessary if mounted to an aircraft operating at high airspeeds, other instrument configurations and capabilities must be considered. Bear in mind, as with fixed applications, the instrument would have to have the capability of determining the visual range under many conditions of precipitation (drizzle, rain, snow, snow grains and pellets, ice crystals and pellets, and hail) and obscurations (mist, fog, smoke, volcanic ash, dust, sand, and haze) (Department of the Air Force, 2002).

In his report, Lujetic (1979) notes that visibility is one of the most complicated of all meteorological elements. The measure of visibility and visual range depends on the characteristics of the atmosphere, the type of viewing instrument, the type of object or light being detected, and the manner by which the object or light is being viewed. According to Lujetic, the primary factors influencing visibility include:

- reflecting power and color of the object,
- reflecting power of the background,
- amount of scattering and absorbing particles,

- position of the sun,
- angular size of the object,
- nature of the terrain between the object and observer,
- contrast of the object, and
- intensity of the light source.

Review of relevant literature and research

In 1984, Lilienfeld and Tomic, of GCA Corporation, under contract to the Air Force Geophysics Laboratory, published a report regarding the development of an expendable visibility sensor (EVS). The sensor was to be part of a parachute-borne package (thus, an instrument able to measure while in motion) designed to determine the vertical dimension of cloud layers and to monitor the local visual range. The instrument within the sensor used for the visibility measurement was a nephelometer. Lilienfeld writes, "These instruments [nephelometers] are based on the detection of light scattered by an ensemble of aerosol particles..." "Traditionally," he continues, "nephelometers used for visual range determinations operate at visible wavelengths. ...with the advent of inexpensive and highly reliable semiconductor sources and detectors that operate in the near-infrared, various types of nephelometric instruments have been developed that incorporate such components." CGA Corporation delivered to the Government three prototype units of the EVS. According to the literature, additional improvements were needed to produce a completely functioning model. When the prototype EVS was compared to integrating nephelometer and transmissometer measurements, it showed very good correlation for a variety of test aerosols such as water fogs, pyrotechnic smokes, tobacco smoke, and various mixtures of these materials.

In 1986, the Air Force Geophysics Laboratory published a report describing an instrument most comparable to the instrument envisioned by the author. It was developed and tested by HSS, Incorporated, of Bedford, Massachusetts, under contract to the Air Force (Hansen et al., 1986). It was a prototype airborne visibility meter (AVM) intended for use on remote piloted vehicles. According to the report, the development program was highly successful. Again, as in the EVS program, improvements were recommended. Further algorithm development was required, along with improvements in data recording systems and data sampling rates. Some design features were problematic. For example, electronic circuit boards were all hand-wired and created electronic noise problems. Certainly, current technology, twenty years advanced, in the areas of electronic circuitry and data processing could solve the recognized problems of the time.

Extensive and multiple searches of the worldwide web, the Defense Technical Information Center and other databases have turned up no other information on a commercially available airborne visibility meter or a similar instrument in use at the present time.

Advances in lasers, radar (*radio detecting and ranging*), lidar (*light detecting and ranging*) and other state-of-the-art technologies may be able to provide the military and civil pilot with the objective visibility data desired. This data, visually presented via a cockpit instrument and, if at all possible, augmented aurally via the intercom system, could provide the necessary information from which an informed decision to proceed with or abort a mission can be made. Prior to the

actual expense of development of such an instrument, this research project will determine if such a concept is practical, would enhance situational awareness, and will serve as a countermeasure to the inadvertent entry into visual conditions responsible for spatial disorientation.

Objective

The objective of the study was to determine if the use of an AVI, providing real-time, objective visual data to the flight crew could increase situational awareness and, thus, prevent entry into atmospheric visual environments that make SD more likely to occur.

Methods

Subjects

Sixteen U.S. Army rated aviators were recruited from Fort Rucker, Alabama. Since no aircraft-specific skills were required, the subjects could be rated in any Army helicopter. Student pilots were disqualified because they lacked actual experience in making mission decisions, a critical aspect and condition of this proof of concept project. All potential subjects were given a full explanation of all procedures involved in participation and signed an informed consent.

Materials

Mock AVI

A mock AVI, with a digital numeric display (developed in-house by USAARL electrical engineers), was mounted using Velcro®, to the center-right of the simulator instrument panel (Figures 1 and 2). This position was chosen because it is one of the few areas on the panel still available to new instruments and does not obstruct the viewing of any existing instruments.

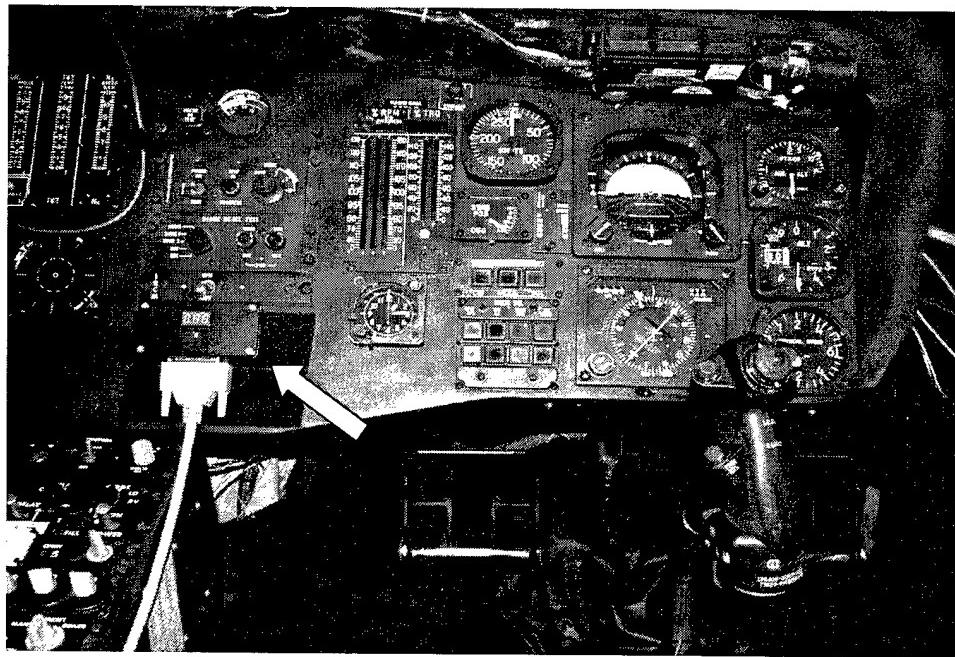


Figure 1. Mock AVI installed in cockpit.

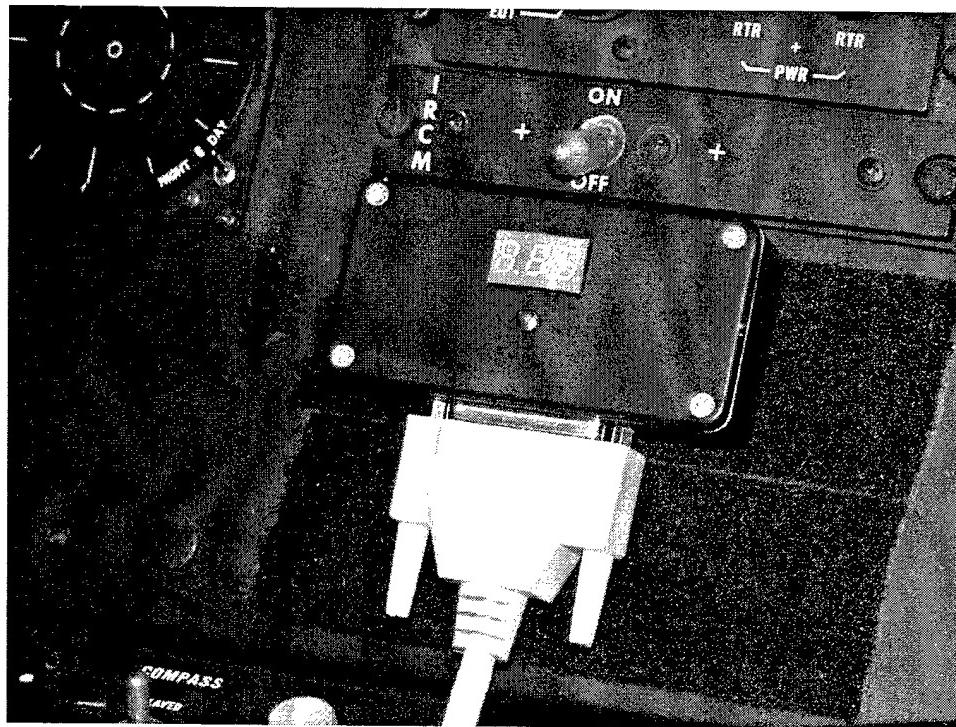


Figure 2. Close-up of mock AVI installed in cockpit.

A remote control (Figure 3) to the mock AVI was manipulated via thumbwheels by the simulator operator/data collector (SO/DC), who set the mock AVI to reflect the simulator's real-time visibility, thereby providing the crew with (simulated) objective visibility data. Note that to make the instrument more useful to the pilot and catch his attention, the mock AVI had a light beneath the digits that blinked whenever the visibility became less than 1 statute mile. Theoretically, in a real device, the light's activation could be manually set at whatever visibility reading desired by the pilot as an alert signal to having encountered conditions less than the minimum visibility allowed. Although not part of this study, an audible cue could be used to further enhance the visual alert signal.

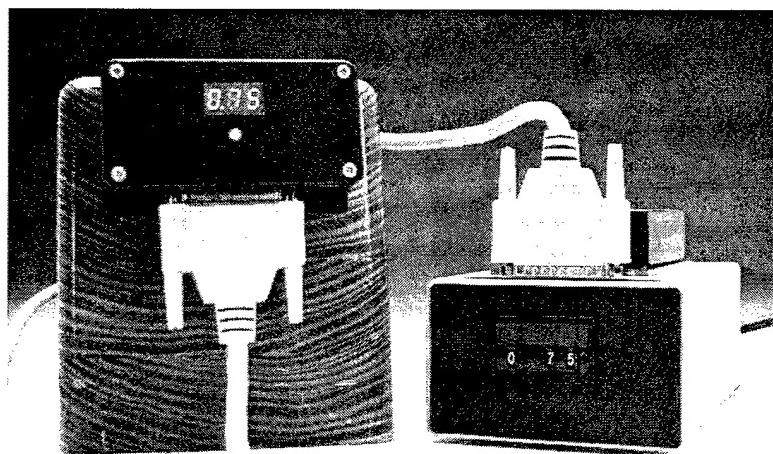


Figure 3. Mock AVI (left) and SO/DC remote control (right).

Demographic questionnaire

A questionnaire (Appendix A) was administered to each aviator prior to their first flight to collect demographic data.

Subjective assessment survey

A subjective assessment survey (Appendix B) was administered to each aviator following their last flight to collect subjective data about the AVI's usefulness, effectiveness and potential as a countermeasure to SD.

Simulator

All flights were conducted in the USAARL NUH-60 research flight simulator. This motion-based system includes an operational crew station (cockpit) and computer-generated visual displays in two forward-looking windshields and two side windows.

All flights were performed in accordance with the flight profile in Appendix C.

Validation of simulator visibility settings. In order to validate the simulator's capability to represent the selected/desired visual range, a test was conducted to identify discrepancies. A hilltop was selected to verify that the simulator visibility setting selected by the simulator operator represented the actual visual range viewed and perceived by the pilot. The test consisted of two separate simulator flights during which distance readings measured along the ground, determined by the onboard GPS (global positioning system), were recorded while viewing the hilltop under degrading visibility at approximately 400 feet above ground level. The GPS distance readings are provided in nautical miles and must be converted to statute miles, the measure used in the U.S. for visibility reporting. A mean was derived from the two readings and then converted from nautical miles (nm) to statute miles (sm). (Note: The simulator uses statute miles for visibility settings.) Table 1, below, contains the raw data collected during the tests and the resulting conversions.

Table 1.
Validation of simulator visibility settings.

Simulator Visibility Settings (sm)	Visual Distance Flight 1 (nm)	Visual Distance Flight 2 (nm)	Mean of Flight 1 & Flight 2 (nm)	Conversion of Mean to Statute Miles
3.75	3.26	3.17	3.22	3.71
3.50	3.09	2.90	3.00	3.45
3.25	2.88	2.81	2.85	3.28
3.00	2.73	2.60	2.67	3.07
2.75	2.47	2.42	2.45	2.82
2.50	2.26	2.28	2.27	2.61
2.25	2.03	2.04	2.04	2.35
2.00	1.86	1.83	1.85	2.13
1.75	1.66	1.56	1.61	1.85
1.50	1.44	1.36	1.40	1.61
1.25	1.18	1.16	1.17	1.35
1.00	0.99	0.96	0.98	1.13
0.75	0.75	0.76	0.76	0.87
0.50	0.53	0.56	0.55	0.63
0.25	0.25	0.25	0.25	0.29

The simulator visibility settings and the mean measured visibilities are plotted and compared in Figure 4 and in the Bland-Altman plot, Figure 5. The maximum difference observed between simulator settings and measured visibilities is 0.13 sm or 686.4 feet. Because of the variability of distance/visibility perception by individual pilots, that distance, while traveling at airspeeds of 100 to 120 knots, is determined to be operationally insignificant. Therefore, the differences were not considered significant enough to warrant adjustments to the simulator settings, thus providing consistency throughout the project.

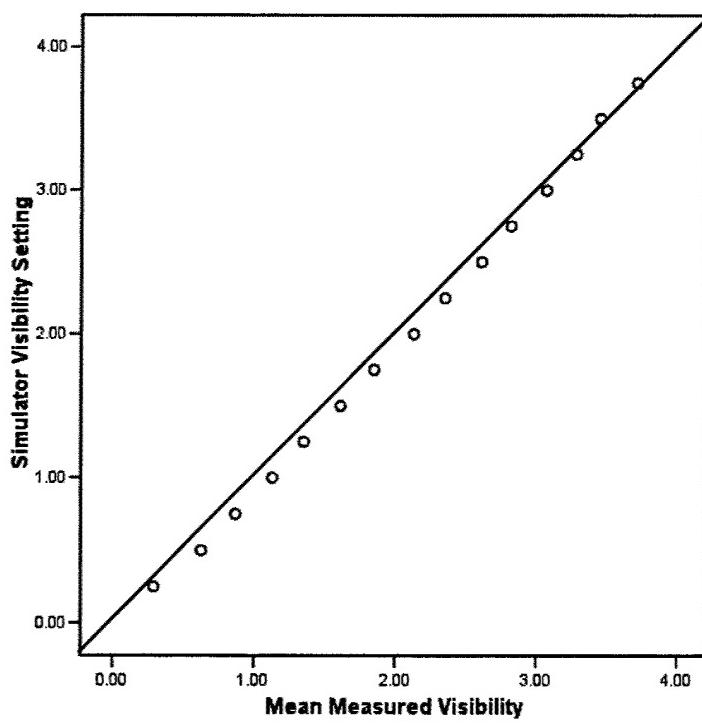


Figure 4. Scatter plot of simulator visibility settings vs. mean of measured visibilities.

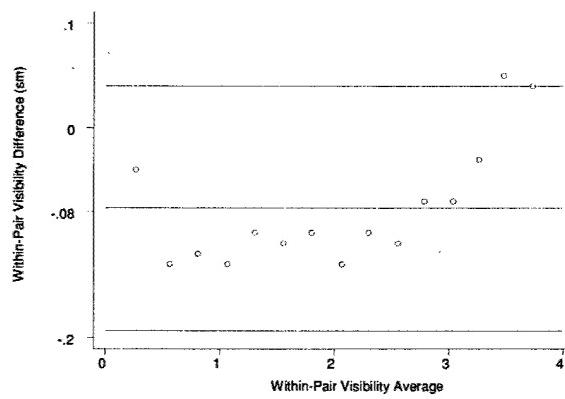


Figure 5. Bland-Altman Plot of Simulator Visibility Setting and Simulator-Determined Visibility Paired Differences versus Average

Procedure

Following completion of the demographic questionnaire (Appendix A) and receiving the pre-mission briefing (Appendix D), each pair of volunteers (a flight crew) flew the first of two 45-minute (approximate time) predetermined tactical missions under VFR in the USAARL UH-60 flight simulator. Half of the crews (four) flew their first mission with a functional mock AVI. The other half flew their first mission without a functional mock AVI. A second mission (the exact flight profile) was performed no sooner than 1 week later with or without a functional mock AVI (opposite to the crew's first flight) to minimize any sequence or recency effects such as correlation and/or familiarity with terrain and degrading visibility.

Pre-mission briefing

All volunteer flight crews received the same pre-mission briefing (Appendix D) prior to each flight, which included the minimum visibility (1.00 sm) allowed by the simulated mission commander for completion of the mission. In other words, based on the simulated mission commander's orders, if the visibility ever decreased below 1.00 sm, the mission must be aborted. (Note: Army aviators, when faced with mission abortion, usually have three options: 1) land the aircraft and wait until conditions improve, 2) turn back to reenter areas of permissible visibility, or, 3) request an IFR [instrument flight rules] (Department of Defense, 2004) clearance and proceed voluntarily according to IFR's. Some missions are aborted involuntarily when the aircrew inadvertently enters instrument meteorological conditions [IMC].) (Note that the volunteers received no visibility-estimation training during this study.)

Data collection and visibility reduction procedures

At least 1 minute after takeoff from forward area refuel point (FARP) 33 (second half of mission), the SO/DC noted the exact time on the Flight Data Collection Sheet (Appendix E) and began a progressive decrease in visibility from 2.5 sm to zero sm visibility in .25 sm increments and at 2-minute intervals. All times recorded were the times presented on the simulator's mission elapsed time (MET) display. The MET corresponding with each reduction of visibility was recorded on the Flight Data Collection Sheet for monitoring the progress of the flight in terms of the degrading visibility. The critical measurement was the deviation, prior to or after, the precise time that the visibility became less than 1 sm (below the mission abort criterion for visibility), with and without the mock AVI. During the flights with the functional mock AVI, the SO/DC ensured that the mock AVI reflected and displayed exactly the real-time simulated visibility.

Mission abort

The SO/DC recorded on the Flight Data Collection Sheet exactly the MET that a decision to abort was made by the aircrews. The time it took from visibility reduction to 1 sm to mission abort (with and without a functional mock AVI) was compared in an attempt to determine the AVI's usefulness, effectiveness and potential as a countermeasure to SD. All missions necessarily aborted, voluntarily or involuntarily, due to the visibility eventually becoming zero.

After the simulated mission commander's guidance, no clues or cues were provided to the volunteer pilots during the flights as to when to abort the mission.

In the event of non-visibility related crashes or tree strikes, the SO/DC was to record the MET and override the crash in order to continue the mission to determine when or if the crew aborted for visibility reasons. (Note: This condition never occurred.)

Feedback

Absolutely no feedback was provided to the flight crews until after their participation in the study was completely finished.

Results

Demographic survey results

Figure 6 illustrates the distribution of the subjects' current position or job.

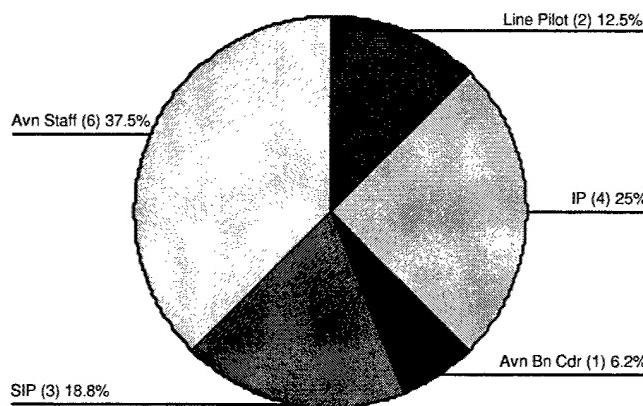


Figure 6. Position/jobs distribution. IP=instructor pilot, Avn Bn Cdr=Aviation Battalion Commander or above, SIP=standardization instructor pilot, Avn Staff Off=Aviation Staff Officer.

The results indicated that 93.8% of the sample population had been, or were currently, pilots-in-command. The majority, 81.3%, indicated that they had achieved flight lead status, thus, qualifying to lead multi-aircraft flight formations. Table 2 shows the distribution of flight activity categories (FACs) (Department of the Army, 1996) and readiness levels (RLs) of the 16 subjects. (See definition of terms.)

Table 2.
Distribution of FAC and RL.

	1	2	3	N/A*
FAC	1 (6.3%)	12 (75.0%)	2 (12.5%)	1 (6.3%)
RL	10 (62.5%)	1 (6.3%)	2 (12.5%)	3 (18.8%)

* FAC and RL do not apply to Department of the Army Civilians (DACS).

The mean total flight hours (fixed and rotary-wing, excluding simulator) logged for the 16 subjects were 2,875 hours with the minimum/maximum being 500/10,000 hours and the standard deviation being 2,255 hours.

Flight results

Mission abort times. As stated earlier, half of the flight crews (four) flew their first flight with an operational mock AVI and the second flight without one. The other half of the crews flew their missions in the opposite order. The zero line on the following two figures (Figures 7 and 8) represents the point in time at which the visibility became less than one statute mile (the mandatory abort point). The plotted points represent the variability from the mandatory abort point based on when the flight crews announced and acted positively to abort the mission. The negative (-) portion of the y axis represents the flight crews' mission abort point prior to the mandatory abort point, while the positive portion represents the flight crews' mission abort point after the mandatory abort point.

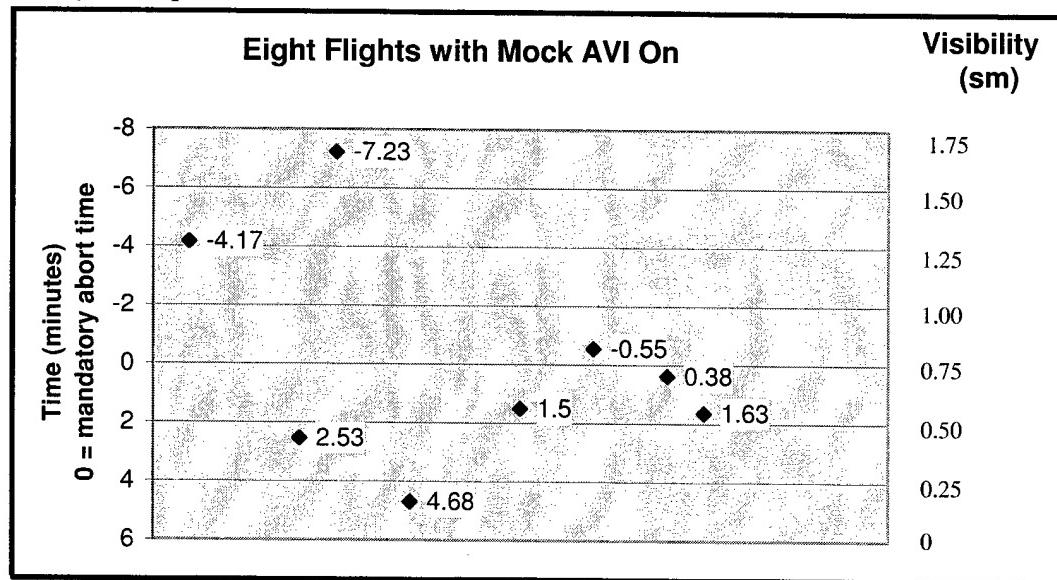


Figure 7. Plot of flight crew mission abort points with a functional mock AVI.

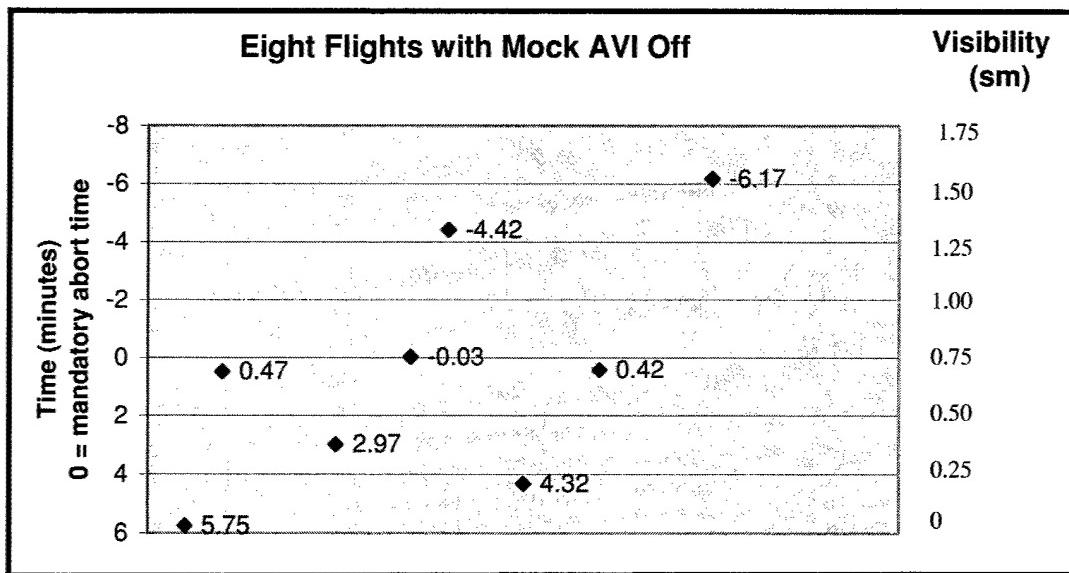


Figure 8. Plot of flight crew mission abort points without a functional mock AVI.

Figure 9 presents the means (\pm SE) of the above plotted points. With the mock AVI on, the mean was -0.15375, or in other words, the average of the actual mission aborts occurred 9.2 seconds before the mandatory mission abort point. With the mock AVI off, the mean was 0.41375 or 24.8 seconds after the mandatory mission abort point. The difference was not statistically significant [paired t-test: $t(7) = 0.23$, $p > .05$ ($p=0.8$)], however, there was an indication of a trend towards more appropriate mission abort times with the use of the AVI. More subjects would be needed to solidify the difference and to determine the full impact of such a device.

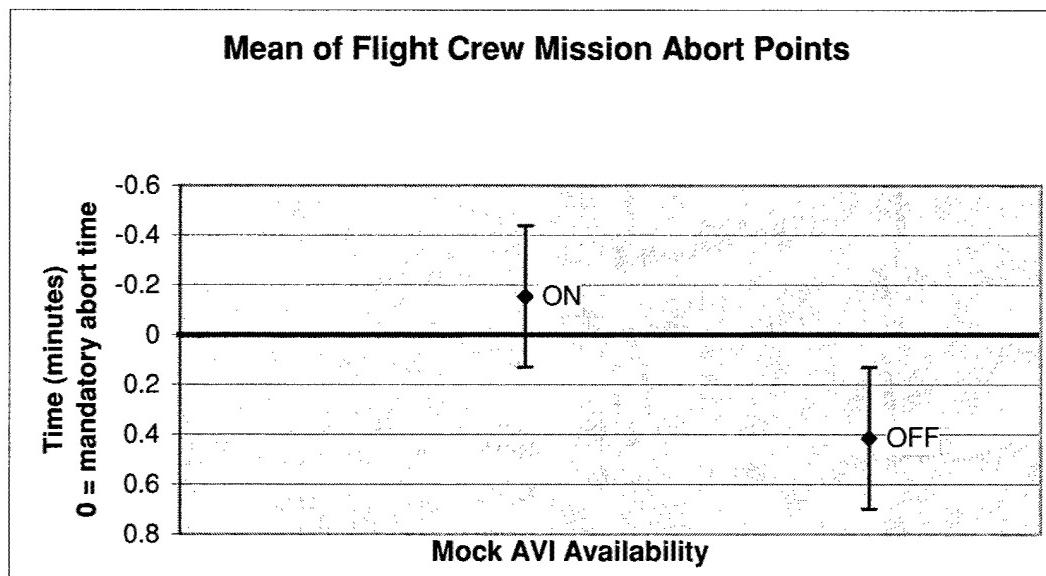


Figure 9. The mean of flight crew mission abort points with and without a functional mock AVI.

Mission abort methods. The method in which the flight crews chose to abort the original, pre-briefed, VFR mission was also noted. It appears that the method is based solely on the preference of the crews rather than an effect of instrumentation or visual conditions as six of the eight crews used the same method for both flights.

Since the protocol dictated the reduction of visibility to continue until it reached zero, one manner of mission abortion would have been inadvertent entry into instrument meteorological conditions. This never occurred during the experiment. All flight crews aborted voluntarily. As stated earlier, the other choices available to flight crews were to land the aircraft and wait until the weather improved, to turn back to the areas where visual flight rules could be complied with, or to enter IMC voluntarily (with or without the appropriate clearance).

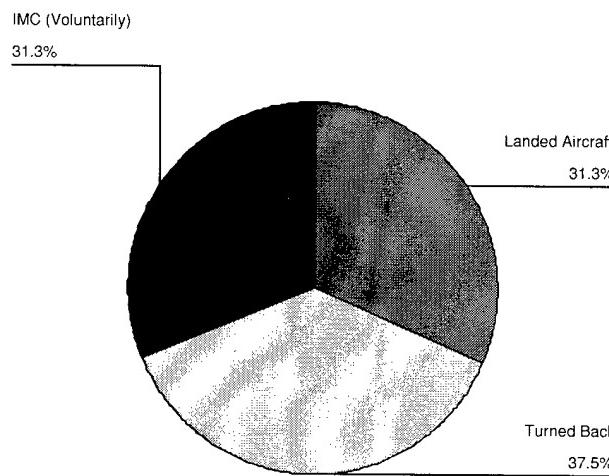


Figure 10. Mission abort methods chosen by subject flight crews.

Mission abort decisions. The researchers thought it might be useful to observe and record whether it was the pilot actually flying the aircraft or the pilot navigating the route who made the final decision to abort the mission. Of the 16 flights conducted, 11 (69%) of the decisions to abort were made by the pilot performing the navigation. In 10 (63%) of the 16 flights, the most experienced pilot (most flight hours) made the decision. Finally, 14 out of the 16 (88%) decisions were made by pilots with experience as flight leaders of multiaircraft formations.

Subjective assessment survey

To gain insight into how the aviators perceived the concept of having an AVI to reference during the conduct of flight missions, a subjective assessment survey was administered immediately following the last of the two flights. (Recall that half of the crews flew their last flight with a functional mock AVI while half flew their last flight without one.) Following are the results of the survey.

Did the AVI affect your ability to recognize those visual conditions that make spatial disorientation more likely? (Yes, negatively = 0; Yes, positively = 11; No = 5)

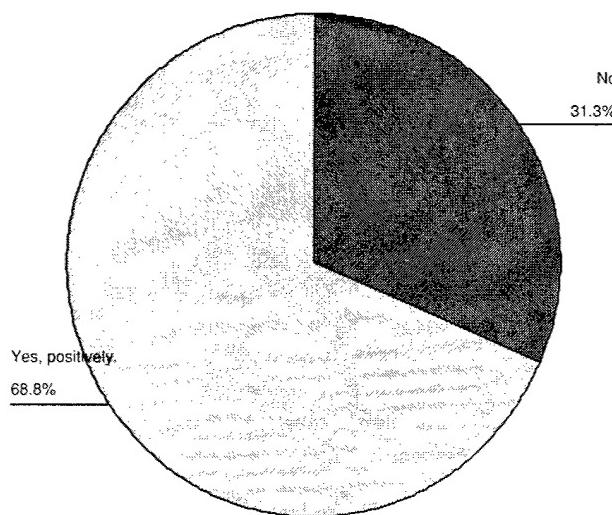


Figure 11. Percentage of responses regarding effect of AVI on recognition of conditions likely to cause SD.

Did the AVI affect your ability to make mission decisions during the flights? (Yes, negatively = 0; Yes, positively = 15; No = 1)

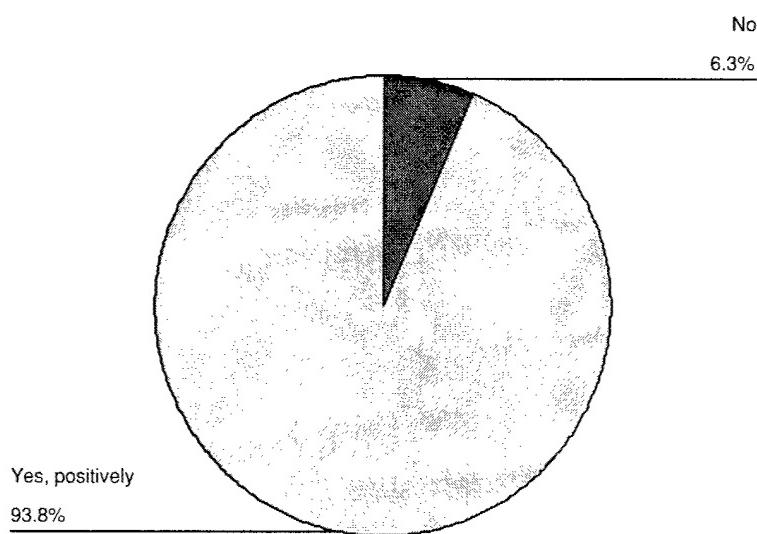


Figure 12. Percentage of responses regarding effect of AVI on ability to make mission decisions.

Did the AVI affect your overall situational awareness? (Yes, negatively = 0; Yes, positively = 15; No = 1)

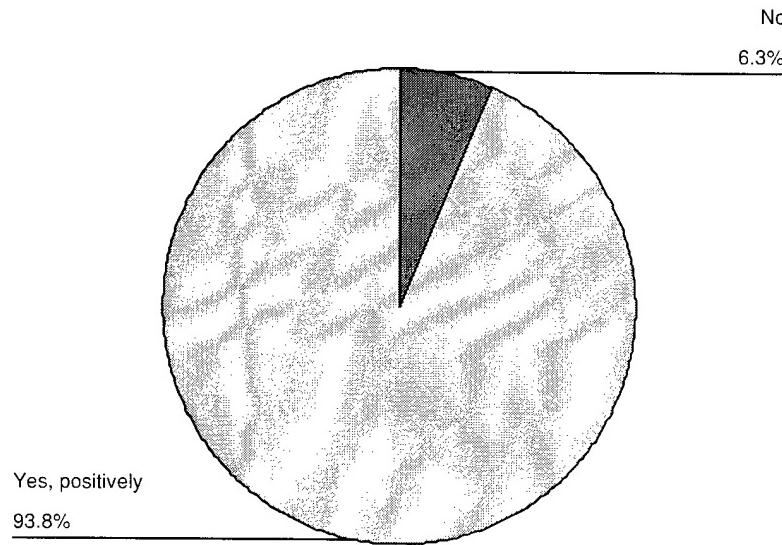


Figure 13. Percentage of responses regarding effect of AVI on overall situational awareness.

Did the AVI affect your crew coordination? (Yes, negatively = 0; Yes, positively = 12; No = 4)

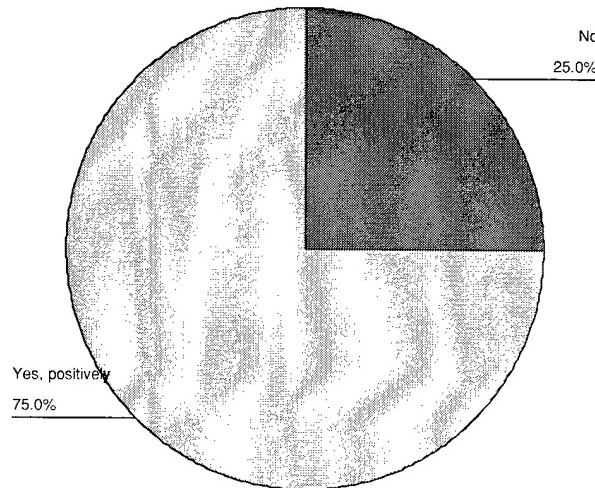


Figure 14. Percentage of responses regarding effect of AVI on crew coordination.

Did the AVI affect crew anxiety due to having actual visibility data during the conduct of mission? (Yes, increased anxiety = 1; Yes, reduced anxiety = 10; No = 1)

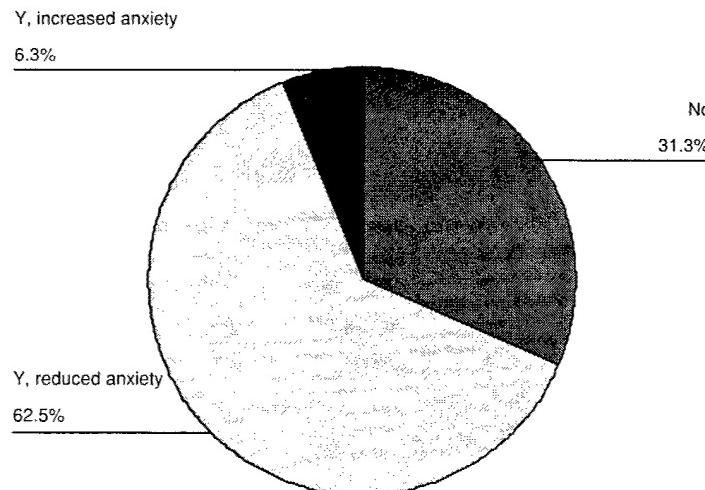


Figure 15. Percentage of responses regarding effect of AVI on crew anxiety.

Did the AVI distract the crew from other tasks essential to the successful completion of the mission? (Yes; No) All 16 subjects (100%) answered "no" to the question.

Might the use of an AVI result in missions being aborted prematurely? (Yes = 5; No = 8; Not sure = 3)

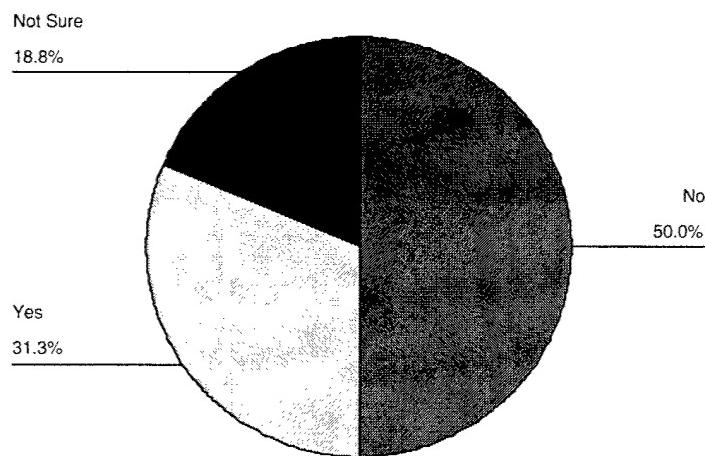


Figure 16. Percentage of responses regarding effect of AVI on premature mission abortions.

Might the use of an AVI result in missions being aborted needlessly? (Yes = 2; No = 9; Not sure = 5)

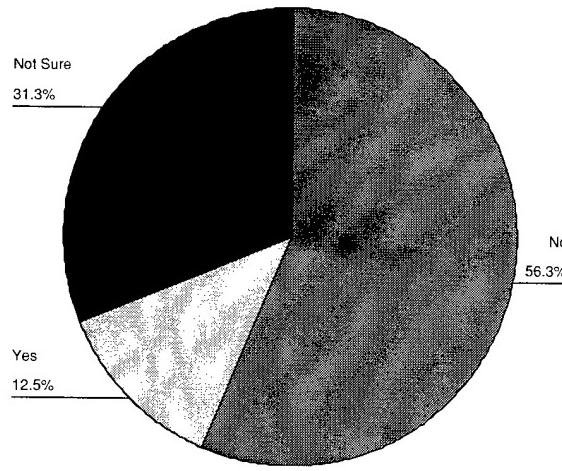


Figure 17. Percentage of responses regarding effect of AVI on needless mission abortions.

Would you recommend the development and fielding of an AVI? (Yes = 16; No = 0)
All 16 subjects (100%) answered "yes" to the question.

Do you feel an AVI could actually prevent aircraft mishaps/accidents? (Yes = 14; No = 2)

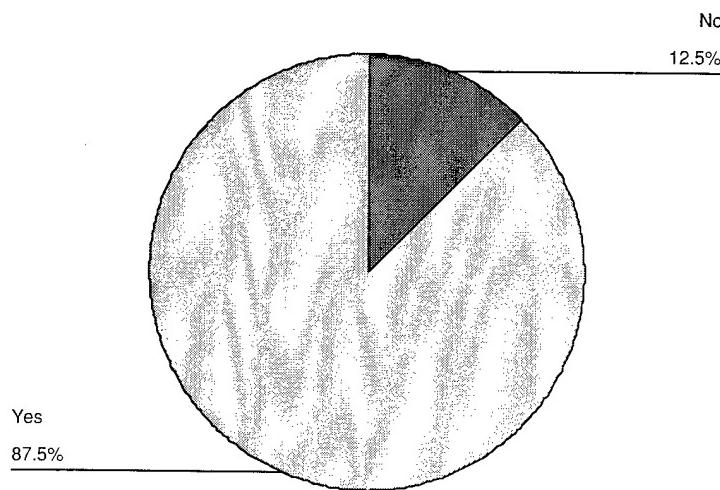


Figure 18. Percentage of responses regarding the AVI's potential to prevent aircraft mishaps/accidents.

Will all aviators in all aircraft types benefit from using an AVI during the conduct of a mission? (Yes = 14; No = 0; Not sure = 2)

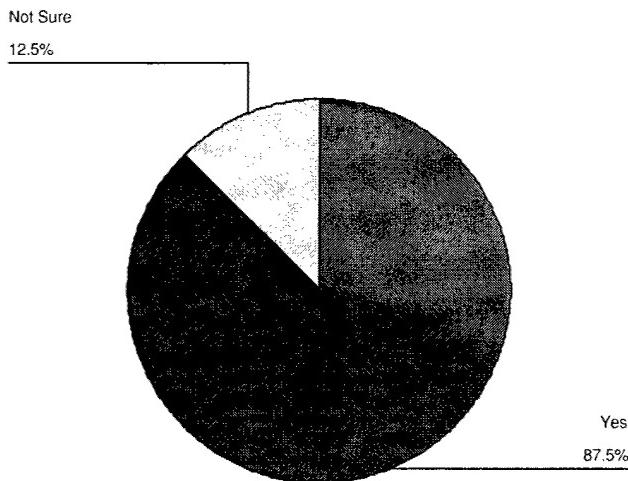


Figure 19. Percentage of responses regarding the benefit of an AVI to other aviators of other

Written Comments. Subjects wrote the following comments on the subjective assessment survey form: (All comments written are listed below.)

"Timing of [the] decision [to abort] was improved by having [a] reference point to start discussing options."

"It [The AVI] helped [the] aircrew make sound decisions with regard to mission abort. [However,] At one point both pilots were fixated on [the] AVI."

"[The] AVI might be a good tool to have to aid low experience crews in making appropriate weather decisions. It is a little more 'black and white' rather than a guess or judgment based on past experience."

"A major obstacle in Army aviation is determining distance and visibility. The AVI would definitely help prevent accidents."

Discussion

Demography

All subjects were volunteers who responded to a solicitation by the principal investigator for subjects in the Fort Rucker (Alabama) area. To participate in the study, the volunteer could be a rated aviator in any type of Army aircraft, since no aircraft-specific skills were required. The researchers disqualified any student pilots who volunteered based on the fact that they lacked actual experience in making mission decisions, a critical aspect and requirement of this proof of

concept. In other words, the researchers felt that subjects with mission experience were critical to the validity of the assessment of this device.

The results of the demographic survey indicate that a satisfactory distribution of pilots holding different jobs and/or positions was achieved in the study. This distribution provided important perspective, from those who fly the missions and those who train other pilots to fly missions, to those who command those who fly the missions.

The ample level of experience of the participant population was evident since all but one had been pilots-in-command and thus, had experience in making final mission decisions affecting the crew of their assigned aircraft. The fact that the average flight hours logged was 2875 and that 81.3% had flight-lead experience was also significant and reassured the research team that the subjects' assessments had the desired credibility.

Flight results

Overall, the data collected during the simulator flights demonstrate the advantages of having real-time visibility information during the conduct of a mission. The objective measure, the average of the mission abort times compared to the mandatory mission abort point, illustrates that the AVI was useful in making more timely decisions in order to avoid visual conditions likely to cause SD. Interestingly, three of the eight flight crews, when operating without the aid of the AVI, actually aborted their mission closer to the mandatory abort point. Also, the furthest abort point from the mandatory abort point occurred with an operational AVI.

It is known that humans are more accurate at judging relative distance than providing absolute estimation of distance (as in the present study), particularly when using computer-generated imagery (Crowley, 1996). This undoubtedly contributed to the variance in these data. One principal function of the AVI is to replace subjective estimation with a source of objective data, thus eliminating a difficult perceptual task.

Investigator observations

It was noted that during flights without the aid of the AVI, there was far more time spent by the crews discussing the visual conditions being encountered, to the exclusion of other flight duties such as performing precise navigation, air traffic control communications, and fuel management procedures. Generally, and possibly naturally, the apparent uncertainty and concern over violating visual flight rules seemed to cause the flight crews to begin questioning the continuance of the mission sooner in the mission.

Although the manner in which the flight crews aborted the missions proved unenlightening, some flight crews demonstrated a surprising disregard for FAA and U.S. Army regulations when mandatory abort visibilities were encountered and acknowledged. Four of the crews continued to fly (two with the AVI and two without) even though the crew announced that they knew they were in violation of flight rules. Five of the 16 missions were aborted by voluntarily entering

IMC even though the crews were not briefed to conduct instrument flight. (They were briefed for a VFR VIP mission, only.) This is a violation of their commander's orders, however, they never hesitated to continue under instrument conditions once the decision was made.

Subjective assessment survey results

Clearly, the most telling indicators of the AVI's potential as an aid to pilots are the results of the subjective assessment survey. The feedback regarding the AVI was overwhelmingly affirmative. The AVI was reported by the vast majority to have affected, in a positive manner: 1) their ability to recognize conditions which may cause SD, 2) their ability to make mission decisions, 3) their overall situational awareness, and 4) their crew coordination. The majority of pilots stated the AVI reduced crew anxiety and created no distraction to the crew from essential mission tasks. Half or better answered that they didn't think the AVI would result in missions being aborted prematurely or needlessly. All subjects recommended the development and fielding of an AVI. As for whether it would be of benefit to all aircraft type pilots, all but two (who answered "not sure") responded that it would.

Conclusions

Spatial disorientation remains a formidable hazard to military and civil aviation. In order to mitigate this hazard, aviators must be provided the tools to make sound and informed mission decisions. Part of this process is the need to accurately assess changing weather conditions. Since atmospheric visibility is one of the most important criteria on which flight rules and mission abortions are based, it seems apparent that any assistance to the flight crew in determining objective visibility data would be of great benefit. In general, data from this proof of concept investigation indicate that an AVI would be a useful tool, is favorably received by aircrews, and a countermeasure to SD.

Recommendations

Based on the findings and conclusions of this proof of concept project, it is recommended that the development of an AVI be continued, a USAARL Small Business Innovative Research (SBIR) proposal topic be submitted for consideration and an invention disclosure be filed in pursuit of a new use patent. (Note that any actual AVI prototype should include auditory cueing, a feature not tested in the mock device tested here.)

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Definition of terms

The following terms are defined for clarity and understanding:

Department of the Army Civilian (DAC): For the purposes of this report, civilian pilots employed by the Army as civil servants to operate aircraft and train Army aviators.

Line Pilot/Army Aviator: A qualified aviator who is a current member of the active Army or National Guard.

Flight Activity Category (FAC): FACs (1,2,3) are designated by a commander based on the proficiency required by a particular aviator in a specific job or position. FAC levels are significant in that they mandate minimum semiannual aircraft and annual simulator hourly requirements for an aviator (Department of the Army, 1996).

IFR (instrument flight rules): Rules governing the procedures for conducting instrument flight. Also a term used by pilots and controllers to indicate type of flight plan. (Department of Defense, 2004)

IMC (instrument meteorological conditions): Meteorological conditions expressed in terms of visibility whereas reference to aircraft instruments is required to maintain the aircraft's attitude, position and/or track.

Night (unaided): Condition of flight between official sunset and sunrise during which night vision goggles are not utilized.

NVG (night vision goggles): Condition of flight between official sunset and sunrise during which night vision goggles are utilized.

Readiness Level (RL): RLs (1,2,3) are the levels of an aviator's proficiency to perform the unit's mission. An RL1 aviator is ready to perform a combat mission, whereas an RL3 has yet to demonstrate proficiency in basic flight tasks (Department of the Army, 1996).

Simulator Operator/Data Collector (SO/DC): A person qualified by the USAARL Flight Systems Branch Standardization Instructor Pilot to operate and collect data in the USAARL AEROMED NUH-60 flight simulator.

USAARL: The United States Army Aeromedical Research Laboratory conducts research to prevent or minimize health hazards in the military operational environment and to sustain the aviator's individual performance.

USASC: The United States Army Safety Center is responsible for conducting accident investigations on selected aviation accidents. The Safety Center maintains a database of all Army accidents.

VFR (visual flight rules): Rules that govern the procedures for conducting flight under visual conditions. The term “VFR” is also used in the United States to indicate weather conditions that are equal to or greater than minimum VFR requirements. In addition, it is used by pilots and controllers to indicate type of flight plan. (Department of Defense, 2004)

VMC (visual meteorological conditions): Meteorological conditions expressed in terms of visibility whereas reference to aircraft instruments is not required to maintain the aircraft's attitude, position and/or track.

Appendix A.

Demographic Survey.

**United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama**

Demographic Survey

Please circle the responses that most accurately answer the following questions.

1. What terms best describe your current position or job title. Circle all that apply.

Line Pilot	Unit Trainer
Instructor Pilot	Standardization Instructor Pilot
Aviation Platoon Leader	Aviation Staff Officer (any level)
Aviation Company Commander	Maintenance Test Pilot
Aviation Battalion Commander or above	

2. Are you currently or have you ever been a pilot-in-command (include limited PC duties)?

Y N NA

3. Are you currently or have you ever been a flight lead?

Y N NA

4. What is your current Flight Activity Category (FAC) designation?

1 2 3 NA

5. What is your current Readiness Level (RL)?

1 2 3 NA

6. How many total flight hours (fixed and rotary-wing) have you logged (excluding simulator)?

Appendix B.
Subjective Assessment Survey.

United States Army Aeromedical Research Laboratory
Subjective Assessment Survey

Subject ID _____

Please circle the answers to the following questions and add comments on back. Remember, consider both flights: with and without the AVI.

1. Did the AVI affect your ability to recognize those visual conditions that make spatial disorientation more likely?

Yes, negatively. Yes, positively. No

2. Did the AVI affect your ability to make mission decisions during the flights?

Yes, negatively. Yes, positively. No

3. Did the AVI affect your overall situational awareness?

Yes, negatively. Yes, positively. No

4. Did the AVI affect your crew coordination?

Yes, negatively. Yes, positively. No

5. Did the AVI affect crew anxiety due to having actual visibility data during the conduct of mission?

Yes, increased anxiety. Yes, reduced anxiety. No

6. Did the AVI distract the crew from other tasks essential to the successful completion of the mission?

Yes No

7. Might the use of an AVI result in missions being aborted prematurely?

Yes No Not sure

8. Might the use of an AVI result in missions being aborted needlessly?

Yes No Not sure

9. Would you recommend the development and fielding of an AVI?

Yes No

10. Do you feel an AVI could actually prevent aircraft mishaps/accidents?

Yes No

11. Will all aviators in all aircraft types benefit from using an AVI during the conduct of a mission?

Yes No Not sure

Appendix C.

Research Flight Profile.

Research Flight Profile

WPT #	Course Distance	ETE	Maneuver Description	WPT Description/ Coordinates
			VMC takeoff 020° from Harris Army Airfield	
1	296° 16.6 km	5+00	120 KIAS	Bridge 21S VK 9950067300
2	284° 16.5 km	4+20	120 KIAS	Point in Space 21S VK 8305065900
3	280° 15.5 km	5+00	100 KIAS	“T” Intersection 21S VK 6745063550
4	229° 11.0 km	3+30	100 KIAS	Point in Space 21S VK 6190053950
5	089° 8.3 km	3+40	100 KIAS, LAND 035°	FARP 33 21S VK 6970056800
6	269° 8.3 km	3+30	100 KIAS	Point in Space 21S VK 6190053950
7	261° 13.2 km	4+30	100 KIAS	Point in Space 21S VK 5010047900
8	182° 16.0 km	5+12	100 KIAS	“Y” Intersection 21S VK 5485032500
9	135° 15.9 km	4+18	120 KIAS	Bend in Road 21S VK 6850024500
10	235° 17.8 km	5+12	120 KIAS, LAND 290°	Seaside AAF 21S VK 587501010

Appendix D.

Pre-mission Briefing.

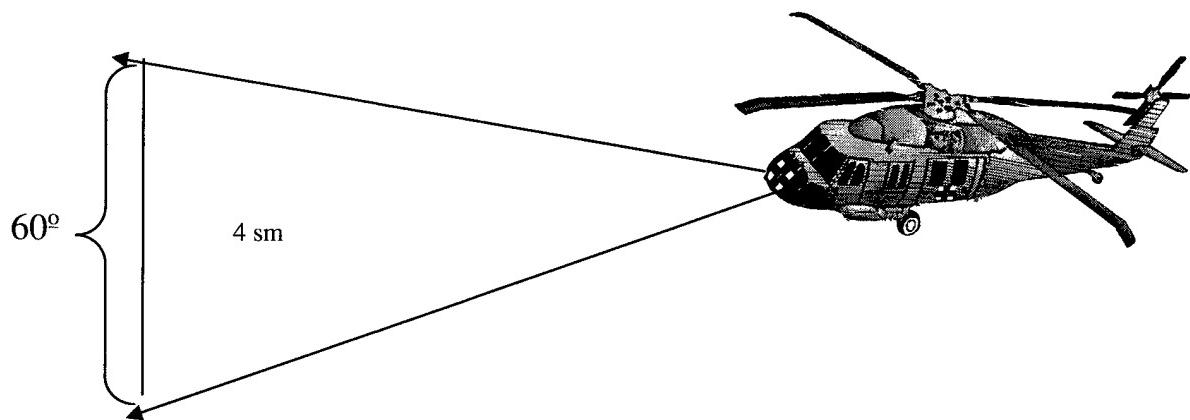
PREMISSION BRIEFING:

Your crew has been assigned a VFR VIP transport mission. You will depart Harris Army Airfield via a preplanned route. A map and enroute card will be furnished with coordinates and prescribed headings and airspeeds. You must follow these headings and airspeeds in order to comply with prearranged clearances through restricted areas. You will proceed to FARP 33 (VK 69705680), which is located in one of these restricted areas, in order to pick up General Purpose who will then be transported to Seaside Army Airfield. You will also receive an instrument package with appropriate airfield frequencies. The frequency to FARP 33 is 38.65.

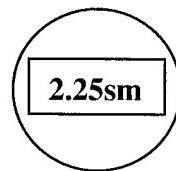
Both airfields lie within Class D airspace. Once outside of the Class D airspace, the entire route proceeds through areas where the floor of Class E airspace begins at 700 feet AGL. Below the Class E is Class G to the ground.

Weather for the entire area is forecast, ETA through one hour, to be 33004kt 7sm few020 sct040. The high-pressure system, which has dominated the area for the last two days, continues to move off to the southeast being replace by a moist cold front, which may produce periods of low visibility. Look for partly cloudy skies, with winds out of the northwest at five knots or less. The high temperature for the pm period will reach into the low 80's.

The aircraft is equipped with a new device called an AVI (Airborne Visibility Indicator) that has the capability of providing visibility readings during the flight. The device reads the visibility from the nose of the aircraft forward up to 4 statute miles and includes an area 30 degrees either side of centerline. Its operation has been intermittent and may be inoperable during this flight.



The visibility information will be displayed on the cockpit instrument panel as an indicator with a digital readout in hundredths of statute miles such as illustrated below:



The mission abort criteria for weather for this VFR mission is 500 and 1.

Any questions?

Appendix E.
Flight Data Collection Sheet.

A Proof of Concept of an Airborne Visibility Indicator (AVI)

Flight Data Collection Sheet

Run ID: _____.

AVI Functional: Y N

<u>Visibility</u>	<u>Reduction MET</u>	<u>Voluntary Mission Abort MET</u>
2.25 sm	_____	_____.
2.00 sm	_____	_____.
1.75 sm	_____	_____.
1.50 sm	_____	_____.
1.25 sm	_____	_____.
1.00 sm	_____	_____.
0.75 sm	_____	_____.
0.50 sm	_____	_____.
0.25 sm	_____	_____.
0.00 sm	_____	Involuntary Mission Abort

Crash/Tree Strike MET (if applicable):

Method of Abortion (circle):

1. Landed aircraft
 2. Turned back
 3. Entered IMC voluntarily
 4. Inadvertent entry into IMC
 5. Other (explain) _____

Remarks: